CONSEIL PERMANENT INTERNATIONAL POUR
L'EXPLORATION DE LA MER
CHARLOTTENLUND SLOT, DANEMARK

# RAPPORTS

ET

# PROCÈS-VERBAUX DES RÉUNIONS

VOLUME CVIII

PART II

## LIGHT MEASUREMENTS

EN COMMISSION CHEZ
ANDR. FRED. HØST & FILS
COPENHAGUE

Août 1938

# CONTENTS

1. H. H. Poole: The Effect of Surface Conditions on the Intensity and Angular Distribution of Submarine Daylight ..... 3
2. Hans Pettersson: Measurements of the Angular Distribution of Submarine Light ..... 7
3. Michael Graham: Trial of Methods of Measuring Transparency of Sea Water ..... 13
4. E. K. Gabrielsen und E. Steemann Nielsen: Kohlensäureassimilation und Lichtqualität bei den Marinen Planktondiatomeen. (Vorläufige Mitteilung) ..... 19

1

# THE EFFECT OF SURFACE CONDITIONS ON THE INTENSITY AND ANGULAR DISTRIBUTION OF SUBMARINE DAYLIGHT.

BY

H. H. POOLE.

IT is generally recognised that weather conditions have a large effect on the percentage of incident daylight that is cut off by the surface of the sea. When the water is entirely unruffled by wind only a small percentage of the light is reflected, the exact proportion being calculable by Fresnel's formulae if the angular distribution of the incident light is known; the remainder is transmitted, so that the surface loss amounts to some 6·5 per cent. with diffuse daylight, falling to about 2 per cent. for vertical sunlight. When, however, the surface is ruffled by waves, especially if their tops are broken by the wind, the loss is found to rise to 30 or 40 per cent. Even so large a loss as 30 per cent. is not of outstanding importance in measurements at considerable depths, as in average water it would only correspond to the effect of an increase of depth of some 2 metres, but if the surface conditions have also an appreciable effect on the average obliquity of the submarine light they will affect the vertical extinction coefficient, and so cause greater changes in the illumination at any level.

The angular distribution of the light under water is evidently of great importance, as it affects, not only the vertical extinction coefficient, but also the ratio of the total illumination at any point (as measured by a spherical photometer surface sensitive to light from all angles) to the vertical illumination, as usually measured with a horizontal plane photometer surface. As this total illumination is the most important factor in photosynthesis, recent direct measurements of the angular distribution of the illumination are of great value (Petterssson *et al.*, 3), since they enable the ratio of the total to the vertical illumination to be found. They have so far, however, only been carried out under calm conditions, and it is worth while considering what effects we should expect to be produced by wind and waves.

## The Measurement of Surface Losses.

It is usual to take the illumination on the upper surface of a horizontal plane as a measure of the submarine light. In order that this may be a clearly-defined quantity it is necessary that th surface should be freely exposed to all rays comin from any point above the horizon, and that it b affected by oblique rays in accordance with th cosine law. This means that any rim surroundin the surface should be as low as possible in com parison with its diameter, and that if possible matte surface should be used. Unfortunately, th diffusing and transmitting properties of an roughened surface are entirely altered by overlyin water, so that for marine measurements — even fo air measurements in the presence of rain or spra — a polished surface is preferable. We can mak suitable correction for reflection losses for light o any given angular distribution by means of Fresnel' formulae (4). For glass of refractive index 1·5 the correction for pure sunlight of 30° altitude, o for the light from a uniform sky, amounts to abou 6 per cent., falling to zero for vertical sunligh (since the photometer is standardised in perpendi cular light), and rising to large values for low angle sunlight.

Since the rectifier photo-cell, which is nov generally used for marine work, must be mounte behind a strong glass window in a water-tight cas it is difficult to avoid excessive screening of low angle light by the rim if we use a clear windo and employ the sensitive surface of the cell as th receiving surface. Moreover, as there are severa polished surfaces involved reflection corrections fo oblique rays become much more important an difficult to calculate, and, when such a photometer is submerged, it is totally insensitive to any ra making an angle greater than 48·5° with th perpendicular, as this will undergo total reflectio at the inner surface of the glass window, and s fail to reach the cell. Just below a perfectly smoot water surface there will be no rays making an angl with the vertical greater than 48·5°, but in th presence of ripples, such rays will occur, so that such a photometer is useless for measuring the surface loss of light.

In order to avoid this loss of oblique rays we must use an opal diffusing glass as a receiving surface, allowing the light transmitted and scattered by the opal to act on the cell. This opal glass

which must be polished on its upper side, at least) must be mounted above the window and any colour filter used, the intervening spaces being kept filled with water to maintain constant reflection losses between the opal and the cell. Alternatively, we may use an opal window, the colour filters being mounted inside the case and changed by some such device as that used by Utterback (6).

For narrow-angle measurements, as in Petersson's recent work, the photometer is not required to be sensitive to oblique rays, and the average obliquity of the rays passing through the colour filter is small and sensibly constant, so that an opal is unnecessary, and merely reduces the sensitivity.

The reading of a photometer consisting of a sensitive cell mounted behind a diffusing glass depends on the illumination reaching the diffusing layer in the interior of the glass. When we lower such an instrument into water the conditions at the polished upper surface of the glass are changed, and appropriate corrections must be made for the change in the loss of incident light and for the reduction in internal reflection of light scattered back by the diffusing layer inside the glass. We may treat these two sources of error separately, by multiplying the photometer reading by the product of two factors, which we may call the "external reflection factor" and the "internal reflection factor", respectively (1).

Considering first the external reflection factor, we must remember that when the photometer is standardised in air, either by exposure to a known intensity of illumination normal to the surface or by comparison with another photometer in diffuse or mixed daylight, some of the light striking the polished upper surface is lost by reflection, the percentage being about 4 for perpendicular light, and nearly 10 for perfectly diffuse light or for light at 60° angle of obliquity, i.e., for sunlight of 30° altitude. For marine work it is generally sufficiently accurate to treat mixed daylight as being equivalent to perfectly diffuse light and to use the constant for the photometer corresponding to the 10 per cent. loss. The presence of a shallow layer of water above the glass reduces this loss slightly, but as it also increases the loss of back-scattered light (see next paragraph) its nett effect is small. When, however, the photometer is used to measure the illumination in the water (as distinct from that in the air above it) the reflection loss is appreciably reduced.

The internal reflection factor is the more important of the two, as, when the photometer is in air over 40 per cent. of the light reaching the diffusing layer is scattered back, and much of this strikes the upper surface at an angle greater than the glass-air critical angle, and undergoes total internal reflection, thus returning to the diffusing layer and contributing to its illumination and hence to the photometer reading. When the photometer is submerged most of this internal reflection is eliminated, and if the depth of immersion exceeds the radius of the diffusing glass total reflection from the water-air surface does not affect the photometer, so that the sensitivity is reduced. It would appear from such laboratory tests as have been made that the nett effect of the two corrections is to reduce the sensitivity by about 8 per cent., so that the constant found for the photometer for diffuse light in air should be multiplied by 1·09 when the photometer is used under water. As this correction is comparable with the surface loss it is evidently of importance, and further determinations of its value may be desirable.

Many of the early estimates of surface loss were affected by errors due to the neglect of one or both of the reflection correction factors, or by the use of photometers insensitive to oblique rays. Moreover, the measurement of surface loss presents certain practical difficulties. If the waves are large enough to affect the ship it is very difficult to keep the photometer at even an approximately constant small depth of immersion, and the rapid variations in the sub-surface illumination render the determination of the average value difficult. Care must also be taken that the variation in the shading by the ship according as the photometer is just above or just below the surface, does not introduce appreciable errors.

It is customary to estimate the surface loss by extrapolating the illumination curve up to the surface from the shallowest level at which reliable measurements can be made under the existing conditions. In this way values have been obtained ranging from a few per cent. in calm water to over 40 per cent. in rough weather.

Powell and Clarke (5) have made a special study of the problem, and have greatly reduced some of the difficulties by suspending their photometers from a floating tubular structure designed to cast very little shadow. They also used an inverted photometer a few metres above the surface to measure the reflected light, and, by lowering it just below the surface found the light scattered back by bubbles or suspended matter in the upper layers.

As the percentage reflected from a smooth water surface rises with the obliquity of the incident light it is a minimum — about 3 for red and 4 for violet — with high sun, rising to 6 or 7 for cloudy conditions or for medium angle sun, and up to 20 with low sun. It is also increased by roughness of the surface, but, according to Powell and Clarke, the increase in reflection so caused is much less than the surface loss of submarine light occurring under such conditions. These authors obtained evidence that the "surface loss" as usually found includes, not only the loss at the actual surface, but also the effect of a highly absorbing layer, often about 1 metre thick, just below it. They would seem to be justified in claiming that

this effect is due to bubbles carried down by breaking wave tops.

It is a little difficult, however, to account for the loss of radiation. If there is no actual absorption of radiant energy the flux density on a horizontal up-turned photometer above the surface should be equal to the sum of the flux densities on an up-turned submerged photometer and on a down-turned photometer measuring the reflected light. In other words the incident vertical illuminations should equal the sum of the transmitted and reflected vertical radiations, and no amount of scattering should alter this relation. Now Powell and Clarke found that when under rough conditions the transmitted vertical radiation was about 70 per cent. of the incident the reflected radiation was only about 10 per cent., leaving 20 per cent. to be accounted for. If we assume that most of this loss occurs in a layer 1 m. thick just below the surface we must assign to this layer an extinction coefficient 2 to 3 times as great as the average for deeper layers, this excess being produced by the roughness of the water. Moreover the excess extinction must be due to absorption, and not to scattering alone.

The diffusing layer postulated by Powell and Clarke must differ from that in an opal glass in two important respects. In the first place the individual bubbles are probably large compared with the wave length of light, so that the proportion of the illumination scattered in any direction is governed by the laws of reflection and refraction, and not by that of scattering by small particles, and, secondly, only a small fraction of the illumination undergoes multiple scattering in the layer. Moreover, the layer is so thick that appreciable true absorption occurs.

If we estimate the proportion of the incident light reflected and refracted in different directions by a spherical air bubble we find that over 50 per cent. is deviated through angles between 20° and 60°, only about 1 per cent. being deflected through more than 90°. This explains the small effect of the bubbles on the reflected light. Their chief effect must be to add to the diffusion caused by the rough surface above them, so that we should expect that under rough weather conditions the average obliquity of the sub-surface illumination would be considerably increased. This would increase the vertical extinction coefficient in the layer by adding to its effective thickness, though we should hardly expect such a large result as a doubling or trebling of the extinction as would be required in order to produce the given reduction in a layer only 1 m. thick. It is more reasonable to assume that the increased obliquity persists to considerably greater depths, though Clarke's results are in opposition to this view.

The evidence as to the effect of depth on the average obliquity is not very satisfactory. Atkins and Poole concluded, as a result of their work, that the angular distribution of the incident light and the condition of the water surface had little effect on the vertical extinction coefficient at depths below 10 m. They considered that the average obliquity at the deeper levels was chiefly governed by a balance between the effects of absorption, which by filtering out the more oblique rays reduces the average obliquity, and scattering, which increases it. The few results that they obtained with vertical or inverted photometers indicated that the ratios of the horizontal and of the back-scattered to the vertical illumination were approximately constant at different depths. On the other hand the reduction in the vertical extinction coefficient which was found in most (though not in all) of their series might be taken as evidence of the reduction of obliquity with increasing depth, though this is unlikely to be the sole cause of the effect.

Clarke (2) concluded that in western Atlantic waters the average obliquity generally increased with depth, whereas Pettersson's most recent work, which is by far the most reliable that has yet been done on the subject, shows clearly that the average obliquity at 10 m. is less than that at 5 m. under a calm surface with bright sun in Swedish waters.

It is evident that further work on the subject of the angular distribution of submarine light under various conditions of surface and of surface illumination is very desirable, but pending the results of such work we should appear to be justified in assuming that the chief effect of surface disturbance is to increase the average sub-surface obliquity, and hence the vertical extinction coefficient in the shallower layers, the obliquity gradually returning to its equilibrium value in deeper water, as determined by the balance of the effects of absorption and scattering by such suspended matter as may be present.

## References.


(1) Atkins, W. R. G., and Poole, H. H., Phil. Trans. Roy. Soc. Lond., B **222**, 129, 1933.

(2) Clarke, G. L., Rapp. et Proc.-Verb. du Conseil Internat., **101**, 2me partie, No. 3, 1936.

(3) Pettersson, H., Journ. du Conseil, XIII, 1, 1938. Also N. G. Johnsson and G. Liljeqvist, Sv. Hydr.-Biol. Komm. Skr., Hydrografi, No. 14.

(4) Poole, H. H., and Atkins, W. R. G., Journ. Mar. Biol. Ass., **14**, 177, 1926.

(5) Powell, W. M., and Clarke, G. L., Journ. Opt. Soc. America, **26**, 111, 1936.

(6) Utterback, C. L., Rapp. et Proc.-Verb. du Conseil Internat. **101**, 2me partie, No. 4, 1936.

2

# MEASUREMENTS OF THE ANGULAR DISTRIBUTION OF SUBMARINE LIGHT.

BY

HANS PETTERSSON.

IN studies of subsurface illumination one generally measures the light falling on a plane horizontal surface, either that of the light-sensitive organ itself, say of a photo-electric cell exposed behind a pressure-proof glass window, or else on an interposed opal, as recommended by Atkins and Poole (1). In most cases the exposed surface faced upwards, thus receiving light from the upper hemisphere only, of which light the more oblique rays had their effect much reduced, according to the cosine law. Occasionally, however, the light-receiving surface was turned sideways or downwards. C. L. Utterback has of late studied the relation between transmitted light, i.e., of downward direction and upward scattered light, of three different spectral bands, by sending down his photometer case first in its normal position and then inverted (2). Another type of photometer case, enclosing two different cells, one facing downwards and the other upwards, and provided with a three-stranded cable, allowing measurements from both photometers to be made in rapid succession, has for some time been used onboard the Swedish research ship, the "Skagerak" (3).

For certain purposes it is important to know the total flux of light impinging from all directions on a small object suspended in the water. This quantity which, for the sake of brevity, will in the following be denoted by "total illumination", $I_T$, has to be considered when dealing with the heating or the chemical effects of submarine light, as, for instance, in the photosynthesis of unicellular plants, the phytoplankton. It must obviously be larger than the intensity, I, measured in the usual manner, and the ratio between the two quantities, $R_T = I_T/I$, may be expected to vary both with angular distribution of the light falling on the water surface, with the depth, and with the transparency of the water, both above and, to a certain extent, also immediately below the point considered.

The following paper gives a brief review of the results of work planned to find the angular distribution of subsurface light and, incidentally, the value of $R_T$ at different depths. A special technique was developed at Bornö Station for the purpose mentioned. A detailed report by two of the Commission's assistants, Fil. lic. N. G. Johnsson and Fil. kand. G. Liljequist, will be published in a coming issue of *Svenka Hydrografisk-Biologiska Kommissionens Skrifter.*

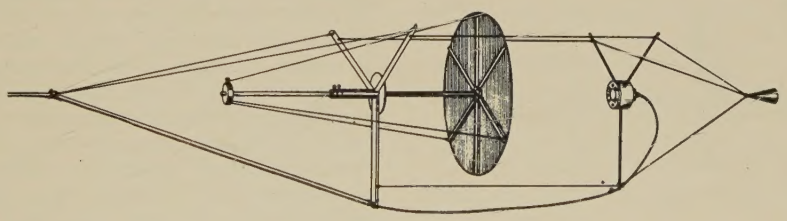


Fig. 1a.

The first instrument used, shown in Figure 1a, was very simple and consisted of the submarine photometer described by Pettersson and Landberg and a superposed shadowing screen which could be fixed at different vertical distances above the photometer, thus cutting out light entering through known fractions of the upper hemisphere. By comparing measurements obtained in rapid succession with increasing distances between photometer and screen, corrected to constant intensity of the light falling on the water surface by means of a deck photometer, one finds the fractions of the total illumination which enter through given zones of the upper hemisphere round the photometer opal, the dimension of which may be neglected in comparison with those of the screen, diameters 600 mm. and 50 mm. respectively.

By means of this arrangement the zonal distribution of submarine light has been studied on clear days, both in the Baltic and in Swedish fjords. In one set of measurements, made near Bornholm at 6, 16 and 26 metres depth the light of maximum intensity was found to come from an inclination to the vertical of 48° in the first-named depth, 33° in the second and rather less than 20° in the third, proving the light to become more vertical in direction with increasing depth, obviously a consequence of the stronger extinction suffered by the more oblique rays.

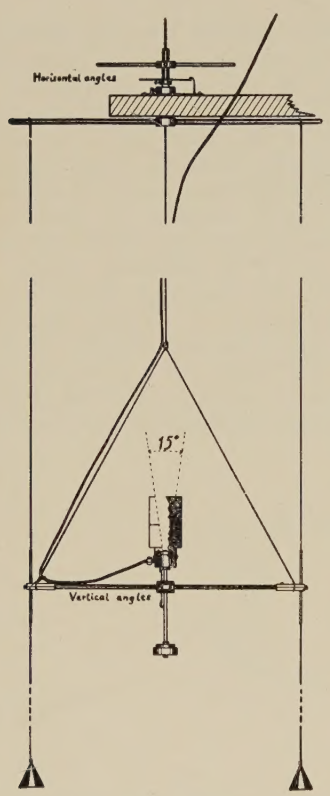


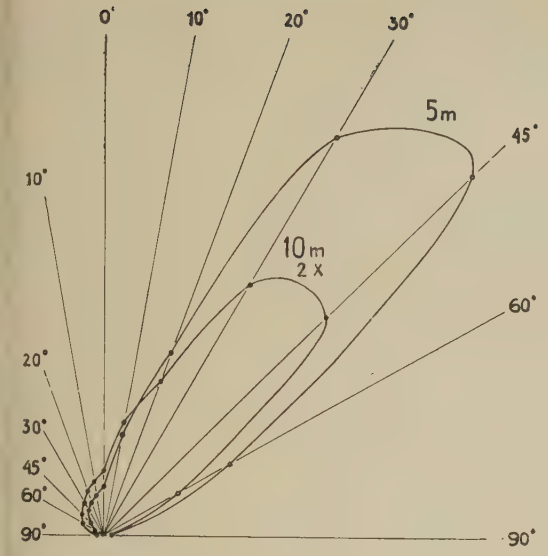

Fig. 1b.

The information obtained with the shadow-screen being less detailed than was considered necessary for the purpose of the investigations, another intrument, shown in Figure 1b, was constructed at Bornö. In this case the cell, a much smaller one, having a light-sensitive surface only 23 mm. in diameter, was provided with a cylindrical screen, attached to it and made with diaphragms, so that the light reaching the cell was limited to a conical bundle of 15° opening. This directional photometer can be turned round a horizontal axis so as to make any desired angle with the vertical. It is kept strictly oriented to a given azimuthal angle by means of a bifilar suspension, but this angle can be changed at will by turning round the disk, shown at the top of the figure and marked like a compass card. The photometer is set to the desired vertical angle when raised above the surface and then sent down to the depth where the measurements are made by turning round the disk by steps of 10°, 15° or more. The whole arrangement is suspended from the extreme end of the light 7-metre crane, mounted on the stern of the "Skagerak". Since the orientation of the ship must remain perfectly steady during a series of measurements, a dead calm is a necessary condition and the ship is kept immobilized by being moored fore and aft. Whereas the vertical angle is varied from 0° to 180°, the horizontal angle is generally varied only through some 240° in order to avoid the shadowing effect from the hull of the ship. Since the curve obtained when plotting the deflection on the galvanometer against the horizontal angle is beautifully smooth and symmetrical to the vertical plane through the sun, the missing parts of the curve can be made good.

So far, this directional photometer has been used in three complete series of measurements, viz., near Bornö in the inner part of the Gullmar Fjord, near the mouth of the fjord and, finally, in the open Koster Fjord near the Norwegian frontier, where one works almost under the same conditions as in the open Skagerak. In all three localities measurements were made at two depths only, viz., 5 metres and 10 metres. At Bornö and in Koster Fjord the sky was clear and there was strong sunlight, whereas near the mouth of the Gullmar Fjord direct sunlight was cut off by light clouds, the light incident on the water surface being almost entirely diffuse. The average elevation of the sun was in all three cases nearly 20°, the refracted rays through a calm surface thus making an angle of 45° with the vertical. No opal was used in front of the cell but instead a green Schott filter VG9, 2 mm. thick, was inserted.

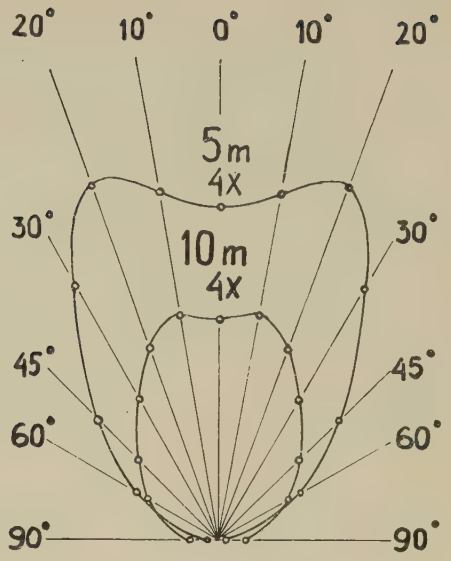
For each depth investigated the "light vectors", i.e., lines proportional to the intensity of the light reaching the cell from different directions, may be constructed, as well as 3-dimensional surfaces enveloping the end points of the light vectors. Drawings representing different sections, vertical and horizontal, through these 3-dimensional surfaces are plotted from the measured values of the light intensity, and from these the total flux of light, $I_T$, reaching the point of observation from all sides can be computed by simple integration. In a similar way the light reaching the cell when exposed at the same level and facing upwards, I, can be computed. The ratio between the two quantities will be the factor $R_T$.

In Figures 2a and 2b vertical sections coinciding with the plane through the sun and at right




Vertical Section
0°–180°

Fig. 2a.




Vertical Section
90°–270°

Fig. 2b.

angles to it are given for the measurements at Börnö, with the proportionality factors by which the light vectors have been multiplied inserted in the figures. As is seen from Figure 2a the light of maximum intensity both at 5 and at 10 metres is very nearly the direction of refracted sunlight, making angles of about 42° and 38° respectively with the vertical. If measurements had been extended to still greater depths, a further diminution of the angles might have been expected. In Figure 2b both depths are seen to have given beautifully symmetrical curves. This light is obviously diffuse in character and the differences in intensity between the two depths are naturally much less than in the other section, demonstrating the rapid increase with depth of the diffuse light relative to that of direct sunlight. The points corresponding to light of horizontal direction, at the bottom of Figure 2a, show an increase with depth in the light scattered sideways and upwards relative to light of downward direction, an increase well borne out by measurements with the double-sided photometer (to be included in the complete report).

The curious dip in the upper parts of both the curves in Figure 2b, seen also though to a less extent in 2a, *round* the vertical, is probably due to an obscuring effect from the suspension and the cable. It does not appreciably affect the numerical results.

Curves much resembling the two samples here given were obtained also from the two other localities although at the mouth of the Gullmar Fjord, where clouds reduced direct sunlight, the preponderance of direct light from the sun was correspondingly reduced and the light-vector surfaces more nearly symmetrical about the vertical.

The values for the ratio $R_T$ computed from these six series of measurements are given below:

| depth | Börnö Gullmar Fjord, clear day, water of fairly high transparency | Mouth of Gullmar Fjord, light clouds, water of medium transparency | Koster Fjord clear day, water of moderately low transparency, maximum quantity of diatoms |
|---|---|---|---|
| 5m. | $R_T = 1 \cdot 48$ | $R_T = 1 \cdot 41$ | $R_T = 1 \cdot 48$ |
| 10m. | $R_T = 1 \cdot 58$ | $R_T = 1 \cdot 29$ | $R_T = 1 \cdot 50$ |

These results indicate that in order to find the total illumination reaching a small object suspended in the water from all directions, one has to multiply the illumination as measured by an ordinary plane photometer by about 1·5 at depths between 5 and 10 metres on clear days with the sun at some 20° above the horizon, whereas on days with diffuse daylight and light clouds the factor is reduced to about 1·35.

The measurements are being extended to greater depths and also to light of other colours nearer the surface.

As an immediate consequence of these results

we may say that the "compensation intensity" found by the author and others at Bornö in 1934 for a raw culture of diatoms exposed at varying depths within a spherical glass bulb (4) to be some 400 lux, should be raised by, say, at least 20 %, since the flasks were exposed near the steep rocks at Bornö, where a considerable part of the oblique rays were cut off. Accordingly 500 lux would be nearer the true compensation intensity for our conditions of work, approximating those under which photosynthesis from a mixed plankton vegetation and population takes place in Scandinavian fjords during the diatom increase. This makes the agreement less satisfactory with the results of Miss Penelope M. Jenkins's careful measurements with pure cultures of *Coscinodiscus excentricus* Ehr. in the English Channels (5), in which only overhead light was utilized, giving a compensation intensity of 360 lux. Even so the discrepancy is easily explained by the different conditions of work and especially by differences in the plankton used.

On the other hand, where inferences on the compensation intensity of free phytoplankton are drawn from experiments with cultures in flasks, accompanied by measurements of the light intensity, the effect of the factor $R_T$ has to be considered, when the results are given in absolute and not in relative figures.

## References.


1. Atkins, W. R. G. and Poole, H. H. 1933. The Photoelectric Measurement of the Penetration of Light of Various Wave-lengths into the Sea and the Physiological Bearing of the Results. Phil. Trans. Roy. Soc. London, B 222, 129.
2. Utterback, C. L. 1936. Spectral Bands of Submarine Solar Radiation in the North Pacific and Adjacent Inshore Waters. Rapp. et Proc.-Verb. du Conseil Internat., CI, No. 4.
3. Pettersson, H. and Poole, H. H. 1937. Measurements of Submarine Daylight. Medd. Göteborgs Högskolas Ocean. Inst., No. 13, pp. 23—26.
4. Pettersson, H., Höglund, H. and Landberg, S. 1934. Submarine Daylight and the Photosynthesis of Phyto-plankton. Medd. Göteborgs Högskolas Ocean. Inst., No. 9.
5. Jenkins, Penelope M. 1937. Oxygen Production by the Diatom Coscinodiscus excentricus Ehr. in Relation to Submarine Illumination in the English Channel. J. Mar. Biol. Assoc., XXII, No. 1, 301.

3

# TRIAL OF METHODS OF MEASURING TRANSPARENCY OF SEA WATER

BY

MICHAEL GRAHAM,

Fisheries Laboratory, Lowestoft.

FROM 3rd to 9th August 1937, a voyage was made in the "George Bligh" to determine the distribution of different kinds of water in the Southern North Sea. We made 44 stations, and worked generally at the depths of 1 m., 10 m., and near bottom. Samples were preserved for determination of salinity and the following determinations were made on the stations when conditions were suitable: temperature, salinity, phosphate, transparency with Lowestoft photometer, transmission of light to submerged photometer, transparency with Secci's disk, and colour. Data for temperature, salinity and phosphate will be published in the Bulletin Hydrographique for 1937. The remaining results are given in Table I.

In all, 19 charts were made of these results, at different depths and using averages of results at all depths, of which four charts referring to the depth of 10 metres will serve to show how the different observations fit each other. Fig. 1 shows the salinity and general topography of the area.

Looking first at the distribution of water of less than 34·0 per mille salinity, this is seen on the English side extending out from the coast of Norfolk as far as and beyond Smith's Knoll. The freshness of this water is no doubt to be ascribed mainly to the river systems of the Humber and Wash, aided no doubt by the Thames. The fresher water off the continental coast seemed to be more evenly aligned parallel with the shore. The salt water supply from the English Channel was distinguishable in the usual area between the masses of fresher water near the coasts. Salter water from the north appears as if pouring in through the Flamborough gateway and over the Dogger Bank itself.

This information became available after the salinities were titrated. It is interesting to see how much of it could have been anticipated from measurement of transparency.

In Fig. 2 are shown the results of measuring the transparency by putting the samples of water in one of the upper glasses of the Lowestoft photometer and balancing by sliding in one of the graded screens.[1]) This screen had first been calibrated to show percentage transmission of the light, by sliding it in so as to give measured differences in deflection of a galvanometer and marking the edge accordingly. Naturally, this calibration was done in harbour with the ship at rest. Comparing Fig. 1

[1]) Journ. du Conseil, XI, 2, Copenhagen, 1936.

Fig. 1. Salinity.

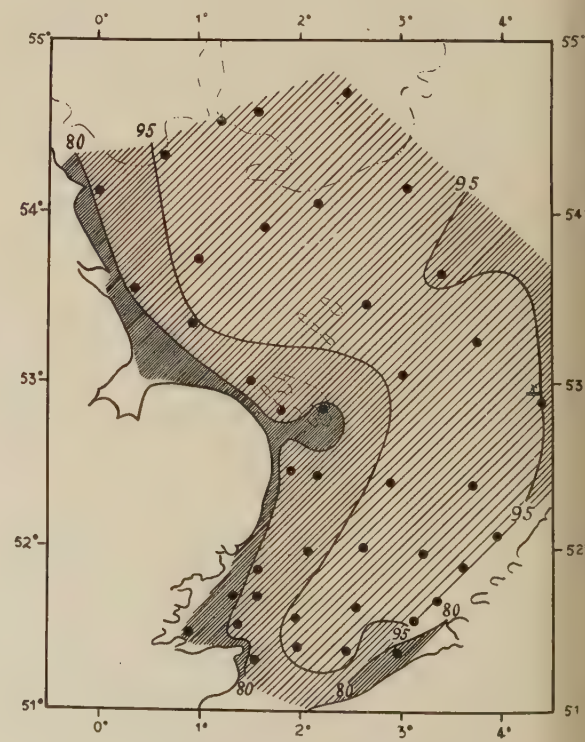



Fig. 2. Transparency by Lowestoft Photometer.

nd Fig. 2, the area of distribution of the clearer, alter water from the Channel and Northern North ea, as distinct from coastal water, is shown in oth. There are, however, differences in detail and, articularly, two faults: firstly, the method is not ery sensitive, so that, for example, there is enerally no distinction between water of above nd below salinity of 34·5 per mille. Secondly, rbidity due to local features, such as Smith's noll, certainly has an effect, just as the local and ther surprising clearness off the Maas would lead the wrong idea that water from the Channel was ose inshore there. This method has, however, the dvantage that it can be used at night.

So far we have dealt with observations at the articular level of 10 m. from the surface. Distri- ution of phosphate at the same depth was, on this ccasion, mainly similar to the distribution of rbidity, that is, it followed the shading of Fig. 2 nd the fresh water of Fig. 1. This is by no means ways the case, but that is not the subject of the resent paper. Temperature at the same level was ot particularly informative. There seemed to be a ngue of cooler water extending east from Flam- orough and grading from there to warm water on e continental coast and in the estuary of the names.

I am indebted to my colleague, Mr. R. S. impenny, for arranging the apparatus for measuring the percentage of light at the surface that is transmitted to the depth of 10 m. The results are shown in Fig. 3. Here there are fewer observations available, because the work could not be done at night. The same limitation applies to the use of Secci's disk, of which the results are shown in Fig. 4. Both methods seem more sensitive than the Lowestoft photometer in distinguishing the most clear from the slightly less clear water. Both have the fault, seen already in Fig. 2, of confusing the transparency or turbidity that the water has acquired locally with that due to its origin and history. Observations on the colour observed against Secci's disk were only made in the later part of the cruise, that is, north of 52° Latitude. The results suggest that this method will not be much help in defining these water masses. The bluest water extended from the second station off Flamborough to the eastward. The yellowest water was near the coast.

The conclusion is that, from the point of view of studying the distribution of water masses in summer, there is much in favour of using Secci's disk. In winter, when most observations would be nocturnal, the Lowestoft photometer would be useful. The most promising method of all is the artificially-illuminated, submerged photometer. This is now in use.

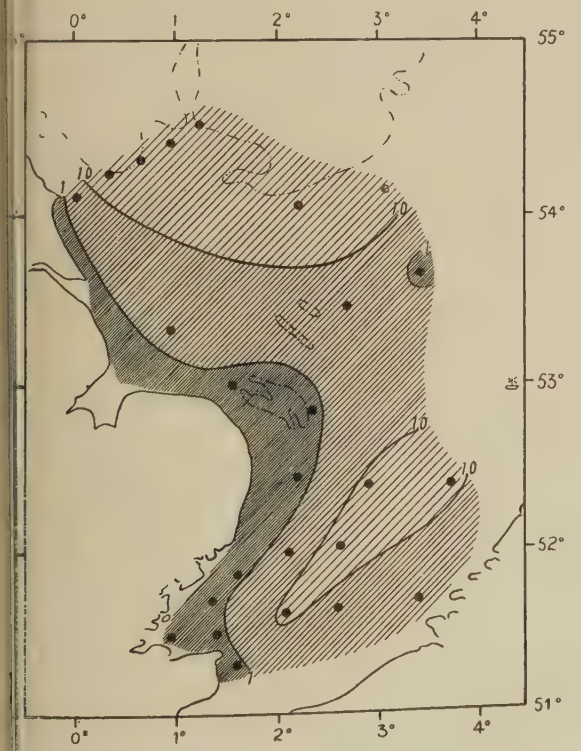



Fig. 3. Transparency by Submarine Photometer.

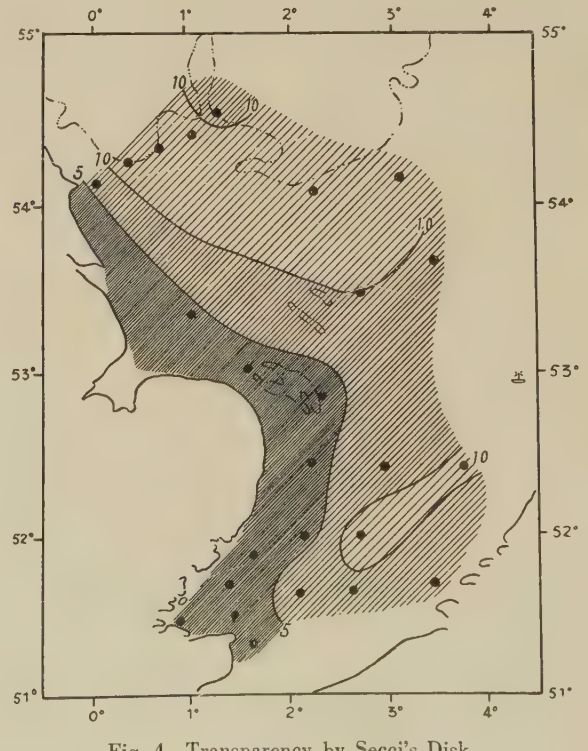



Fig. 4. Transparency by Secci's Disk.

## Table 1.

**Transparency with Lowestoft Photometer, Transparency with Secci's Disk, Transmission of Daylight, and Colour according to Forel's Scale.**
**S.S. "George Bligh", Cruise L 1934.**

S. Reading of Secci's disk.
P. Transmission of daylight as a percentage of that just above sea surface. Measured with a submerged photo-cell, compared with one on the bridge.
Ty. Transparency measured by light transmitted through the 10″ tube of the Lowestoft photometer, expressed as a percentage of that transmitted through distilled water.
F. Colour according to Forel's scale. For example, No. 3 might be called "greenish blue" and No. 9 "yellowish green".
Positions, temperatures, salinities and phosphates will be published in the "Bulletin Hydrographique" for 1937

| Station | Date, 1937 | Time | S. | F. | Depth | P. | Ty. |
|---|---|---|---|---|---|---|---|
| 1 | 3. VIII | 1943 | | | 1 | | 96 |
| | | 1947 | | | 10 | | 94 |
| | | 1951 | | | 25 | | 93 |
| 2 | „ „ | 2312 | | | 1 | | |
| | | 2316 | | | 10 | | |
| | | 2320 | | | 20 | | |
| 3 | 4. VIII | 0329 | | | 1 | | 86 |
| | | 0333 | | | 10 | | 88 |
| | | 0337 | | | 18 | | 86 |
| 4 | „ „ | 0633 | 2·5 | | 1 | | 88 |
| | | 0637 | | | 10 | 0·3 | 86 |
| | | 0641 | | | 15 | | 79 |
| 5 | „ „ | 0835 | 2·4 | | 1 | | 84 |
| | | 0839 | | | 10 | 0·3 | 75 |
| 6 | „ „ | 1347 | 1·1 | | 1 | | 65 |
| | | 1351 | | | 10 | 0·0 | 71 |
| | | 1355 | | | 18 | | 72 |
| 7 | „ „ | 1646 | 2·5 | | 1 | | 83 |
| | | 1650 | | | 10 | 0·4 | 83 |
| 8 | „ „ | 1832 | 2·3 | | 1 | | 80 |
| | | 1836 | | | 10 | | 82 |
| | | 1838 | | | 15 | | 82 |
| 9 | „ „ | 2057 | | | 1 | | 97 |
| | | 2103 | | | 10 | | 96 |
| | | 2107 | | | 30 | | 96 |
| 10 | „ „ | 2317 | | | 1 | | 98 |
| | | 2320 | | | 10 | | 98 |
| | | 2323 | | | 25 | | 98 |
| 11 | 5. VIII | 0125 | | | 1 | | 65 |
| | | 0129 | | | 10 | | 65 |
| 12 | „ „ | 0318 | | | 1 | | 100 |
| | | 0321 | | | 10 | | 100 |
| | | 0324 | | | 20 | | 100 |
| 13 | „ „ | 0521 | 6·5 | | 1 | | 100 |
| | | 0524 | | | 10 | 2·8 | 100 |
| | | 0527 | | | 20 | | 100 |
| 14 | „ „ | 0853 | 9·5 | | 1 | | 100 |
| | | 0856 | | | 10 | 8·0 | 100 |
| | | 0859 | | | 30 | | 100 |
| 15 | „ „ | 1210 | 8·3 | | 1 | | 97 |
| | | 1212 | | | 10 | 10·9 | 100 |
| | | 1214 | | | 45 | | 100 |
| 16 | „ „ | 1440 | 3·8 | | 1 | | 92 |
| | | 1443 | | | 10 | 1·4 | 92 |
| | | 1446 | | | 25 | | 92 |
| 17 | „ „ | 1733 | 11·0 | | 1 | | 100 |
| | | 1736 | | | 10 | 13·0 | 100 |
| | | 1740 | | | 35 | | 100 |
| 18 | 5. VIII | 2023 | | | 1 | | 100 |
| | | 2025 | | | 10 | | 98 |
| | | 2027 | | | 25 | | 98 |
| 19 | „ „ | 2236 | | | 1 | | 100 |
| | | 2238 | | | 10 | | 100 |
| | | 2240 | | | 20 | | 100 |
| 20 | 6. VIII | 0054 | | | 1 | | 90 |
| | | 0058 | | | 10 | | 100 |
| | | 0102 | | | 15 | | 100 |
| 21 | „ „ | 0334 | | | 1 | | 100 |
| | | 0338 | | | 10 | | 90 |
| 22 | „ „ | 0640 | 10·0 | | 1 | | 100 |
| | | 0642 | | | 10 | 12·0 | 100 |
| | | 0645 | | | 20 | | 100 |
| 23 | „ „ | 1040 | 8·3 | | 1 | | 100 |
| | | 1044 | | | 10 | 11·2 | 100 |
| | | 1048 | | | 40 | | 100 |
| 24 | „ „ | 1422 | 4·5 | 9 | 1 | | 90 |
| | | 1425 | | | 10 | 0·4 | 85 |
| | | 1429 | | | 30 | | 80 |
| 25 | „ „ | 1712 | 4·0 | 7 | 1 | | 80 |
| | | 1714 | | | 10 | 0·5 | 80 |
| | | 1718 | | | 35 | | 80 |
| 26 | „ „ | 2118 | | | 1 | | 100 |
| | | 2121 | | | 10 | | 100 |
| | | 2125 | | | 25 | | 100 |
| 27 | 7. VIII | 0107 | | | 1 | | 100 |
| | | 0111 | | | 10 | | 100 |
| | | 0115 | | | 20 | | 100 |
| 28 | „ „ | 0443 | 9·0 | 5 | 1 | | 100 |
| | | 0447 | | | 10 | 9·4 | 90 |
| | | 0451 | | | 35 | | 90 |
| 29 | „ „ | 0834 | 10·0 | 6 | 1 | | 100 |
| | | 0837 | | | 10 | 6·5 | 100 |
| | | 0839 | | | 25 | | 100 |
| 30 | „ „ | 1406 | 12·0 | 4 | 1 | | 100 |
| | | 1409 | | | 10 | 14·9 | 100 |
| | | 1412 | | | 25 | | 100 |
| 31 | „ „ | 1825 | 14·0 | 3 | 1 | | 100 |
| | | 1828 | | | 10 | 17·2 | 100 |
| | | 1832 | | | 65 | | 90 |
| 32 | „ „ | 2130 | | | 1 | | 100 |
| | | 2132 | | | 10 | | 100 |
| | | 2137 | | | 25 | | 100 |
| 33 | 8. VIII | 0041 | | | 1 | | 100 |
| | | 0044 | | | 10 | | 100 |
| | | 0048 | | | 20 | | 100 |

| tion | Date, 1937 | Time | S. | F. | Depth | P. | Ty. |
|---|---|---|---|---|---|---|---|
| 34 | 8. VIII | 0357 | | | 1 | | 90 |
| | | 0400 | | | 10 | | 90 |
| | | 0404 | | | 15 | | 90 |
| 35 | „ „ | 0923 | 5·5 | 8 | 1 | | 90 |
| | | 0925 | | | 10 | 4·9 | 90 |
| | | 0928 | | | 20 | | |
| | | 0931 | | | 30 | | |
| | | 0934 | | | 40 | | 90 |
| 36 | „ „ | 1145 | 15·5 | 3 | 1 | | |
| | | 1147 | | | 10 | 17·1 | |
| | | 1149 | | | 20 | | |
| | | 1153 | | | 30 | | |
| | | 1155 | | | 40 | | |
| | | 1158 | | | 50 | | |
| 37 | „ „ | 1400 | 17·0 | 5 | 1 | | 100 |
| | | 1404 | | | 10 | 19·2 | 90 |
| | | 1408 | | | 20 | | |
| | | 1412 | | | 30 | | |
| | | 1416 | | | 40 | | |
| | | 1420 | | | 50 | | 100 |

| Station | Date, 1937 | Time | S. | F. | Depth | P. | Ty. |
|---|---|---|---|---|---|---|---|
| 38 | 8. VIII | 1634 | 13·0 | 5 | 1 | | |
| | | 1637 | | | 10 | 17·3 | |
| | | 1640 | | | 20 | | |
| | | 1643 | | | 30 | | |
| | | 1646 | | | 40 | | |
| 39 | „ „ | 1908 | 9·5 | 6 | 1 | | 100 |
| | | 1912 | | | 10 | 10·2 | 100 |
| | | 1916 | | | 20 | | |
| | | 1920 | | | 30 | | 100 |
| 40 | „ „ | 2110 | | | 1 | | 100 |
| | | 2114 | | | 10 | | 100 |
| 41 | 9. VIII | 0127 | | | 1 | | 100 |
| | | 0129 | | | 10 | | 100 |
| | | 0132 | | | 15 | | 100 |
| 42 | „ „ | 1332 | 4·2 | 9 | 1 | | 95 |
| | | 1334 | | | 10 | 1·6 | 95 |
| 43 | „ „ | 1917 | 3·7 | 9 | 1 | | 95 |
| | | 1920 | | | 10 | 0·7 | 95 |
| | | 1924 | | | 20 | | 90 |
| 44 | „ „ | 2030 | | | 1 | | 90 |
| | | 2033 | | | 10 | | 80 |
| | | 2037 | | | 30 | | 90 |

4

# KOHLENSÄUREASSIMILATION UND LICHTQUALITÄT BEI DEN MARINEN PLANKTONDIATOMEEN.

(VORLÄUFIGE MITTEILUNG)

VON

E. K. GABRIELSEN UND E. STEEMANN NIELSEN.

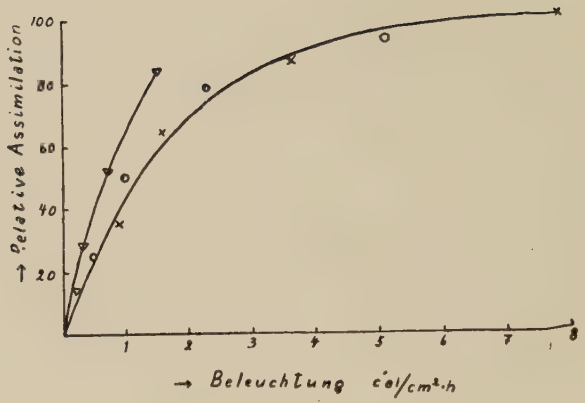



Fig. 1. Versuche am 17. März. ▽ blau-violetter Filter, × gelb-grüner Filter, ○ rot-orange Filter.

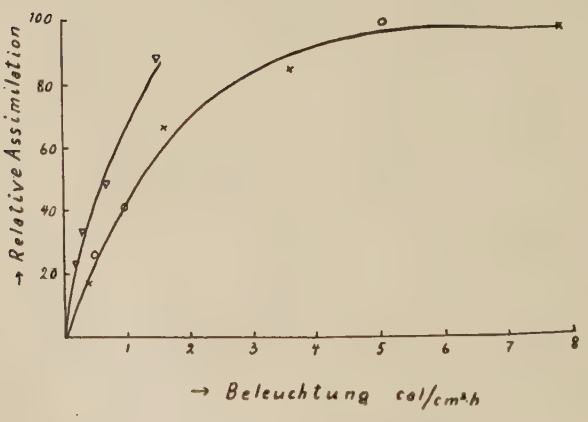



Fig. 2. Versuche am 19. März. Signaturen s. Fig. 1.

Da die spektrale Zusammensetzung des Lichtes im Meere sich nach der Tiefe zu in ausserordentlichem Masse verändert, ist es von ganz besonderer Wichtigkeit, die Abhängigkeit der $CO_2$-Assimilation der marinen Pflanzen von der Lichtfarbe zu kennen. Solche Untersuchungen sind bei den Planktondiatomeen bis jetzt noch nicht vorgenommen.

Bei der vorliegenden Untersuchung wurde Rohplankton vom südlichen Teil des Kattegats benutzt. Es wurden 50 l. Oberflächenwasser während der Nacht von einem Dampfer geschöpft. 6 Stunden später konnten die Experimente im Laboratorium angefangen werden. Die Untersuchungen wurden während des Frühlingsmaximums vorgenommen. Es war ein fast reines Diatomeenplankton. Zooplanktonten waren fast nicht vorhanden, und von den ganz wenigen Peridineen und Flagellaten konnte ganz abgesehen werden. Die Chromatophoren der Diatomeen waren gut braun. Während der ersten Versuchsserie (17. März 1938) hielten sich die Diatomeen völlig schwebend; in der zweiten Serie (19. März 1938) konnte dagegen ein deutliches Sinken bemerkt werden. Um die Zeitdauer der Experimente herabzusetzen, wurde das Plankton mittels Filtration durch Seide Nr. 25 konzentriert. In Tabelle 1 ist die Menge der Diatomeen pro 1 ccm. in den beiden Serien angegeben.

**Tabelle 1**

| | 17./III | 19./III |
|---|---|---|
| Salzgehalt, S ‰ ..... | 24·0 | 23·7 |
| Diatomeen, alle ..... | 48,000 | 28,300 |
| *Acceletonema costatum* ..... | 4,700 | 3,000 |
| *Leptocylindrus danicus* ..... | 16,000 | 12,000 |
| *Chaetoceros*, alle ..... | 26,400 | 11.500 |
| (u.a. *C. compressus, constrictus* und *curvisetus)* | | |

Als Lichtquelle diente eine 3,000 Watt Projektionslampe bei einer konstanten Spannung von 205 Volt. Es wurden Versuche in 3 verschiedenen Spektralgebieten vorgenommen. Hierbei wurden Filter benutzt, die aus Schott'schen Farbgläsern und Küvetten mit Lösungen von Kupfersulphat und Chininchlorid zusammengesetzt wurden. Die Durchlässigkeit geht aus Tabelle 2 hervor.

**Tabelle 2**

| Filter | Durchlässigkeitsgrenzen mμ. | Halbwertsgrenzen mμ. | Schwerpunkt der Durchlässigkeit mμ. |
|---|---|---|---|
| Blau-violett .. | 390—520 | 400—460 | 430 |
| Gelb-grün .... | 470—650 | 500—580 | 540 |
| Rot-orange ... | 580—740 | 610—660 | 635 |

Die Beleuchtungsintensität wurde in cal. pro $cm^2$. und Stunde gemessen. Hierbei wurde ein Photoelement (Selen-Sperrschichtzelle)-Milliampèremeter-System benutzt, das durch Vergleich mit einem absolut justierten Thermoelement-Galvanometer-System geeicht war.

Die $CO_2$-Assimilation wurde auf Grund des Sauerstoffwechsels in $2\frac{1}{2}$-stündigen Versuchen gemessen. Sauerstoff wurde nach der Methode von Winkler bestimmt. Die Planktonaufschlemmung wurde in 15 ccm. Flaschen mit Glasstöpseln verteilt. Die Flaschen wurden zu zwei und zwei in kleinen Wasserbädern angebracht, die in verschiedenem Abstand von der Lichtquelle aufgestellt wurden. Die Atmung des Planktons wurde in Flaschen, die mit schwarzem Stoff zugedeckt waren, gleichzeitig gemessen. Die Temperatur der Wasserbäder war konstant 9°C. Die Versuche wurden nacheinander in den verschiedenen Spektralgebieten ausgeführt. Als Kontrolle dafür, dass die Assimilationstätigkeit der Planktonalgen sich nicht während der ganzen Serie veränderte, dienten Assimilationsbestimmungen in optimaler Beleuchtung mit unfiltriertem Licht (10,000—15,000 Lux).

Die Resultate von zwei Versuchsserien werden durch die Kurven Fig. 1 und 2 gegeben. Die Assimilationsintensität ist in Prozenten von der Leistung im optimalen weissen Licht berechnet.

Die Resultate der beiden Serien stimmen gut überein. Die $CO_2$-Assimilation ist am kräftigsten in blau-violettem Licht. Es war nicht möglich, einen Unterschied in der Wirkung von grün-gelbem und rot-orange Licht zu beobachten. Im Verhältnis zum blauen Licht war die Wirkung in diesen Spektralgebieten ungefähr halb so gross. Mit dieser maximalen Ausnutzung des kurzwelligen Lichtes weichen die Diatomeen von allen andern bis jetzt untersuchten Pflanzen ab.

Die vorliegende Untersuchung ist mit Unterstützung vom Carlsberg-Fond im pflanzenphysiologischen Laboratorium der kgl. tierärztlichen und landwirtschaftlichen Hochschule, Kopenhagen, ausgeführt. Die Lichtmessungsapparate sind im biophysikalischen Laboratorium der Universität, Kopenhagen, justiert worden.